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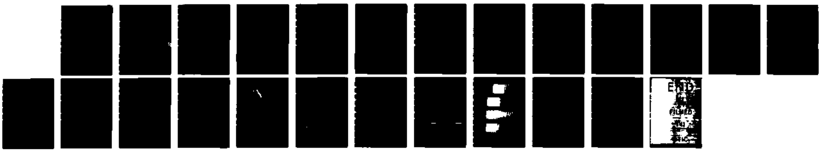

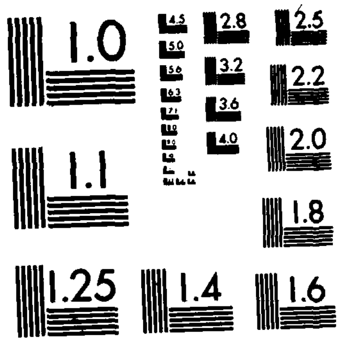

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Acoustic transmission loss and detailed environmental measurements were made in May 1978 along a 900 km track in the Western North Aiantic transecting Slope Water, the Gulf Stream, and Sargasso Sea. The sound source was an omnidirectional 88.8CW projector towed at a depth of 30 m. The signal was received at a bottom-mounted hydrophone situated near the DSC axis in the vicinity of Bermuda.

When the source was located in the Gulf Stream, sound propagation was degraded by as much as 10 dB compared to values when the source was in Slope Water or

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Sargasso Sea. Ray traces with the source in the Gulf Stream showed strong downward refraction, driving most of the energy into the bottom resulting in the high propagation loss.

Transmission loss predictions from the GRASS and PE models were compared to the experimental data. The PE model successfully predicted the high transmission loss in the Gulf Stream while the GRASS model did not. Both models predicted convergence zone spacing in the Sargasso Sea to within 10 percent of the experimental data.

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TECHNICAL NOTE

COMPARISON BETWEEN MEASURED AND THEORETICAL TRANSMISSION LOSS ACROSS THE GULF STREAM

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NOVEMBER 1979

ABSTRACT

Acoustic transmission loss and detailed environmental measurements were made in May 1978 along a 900 km track in the Western North Atlantic transecting Slope Water, the Gulf Stream and the Sargasso Sea. The sound source was an omnidirectional 88.8 CW projector towed at a depth of 30 m. The signal was received at a bottom mounted hydrophone situated near the DSC axis in the vicinity of Bermuda.

When the source was located in the Gulf Stream, sound propagation was degraded by as much as 10 dB compared to values when the source was in Slope Water or Sargasso Sea. Ray traces with the source in the Gulf Stream showed strong downward refraction, driving most of the energy into the bottom resulting in the high propagation loss.

Transmission loss predictions from the GRASS and PE models were compared to the experimental data. The PE model successfully predicted the high transmission loss in the Gulf Stream while the GRASS model did not. Both models predicted convergence zone spacing in the Sargasso Sea to within 10 percent of the experimental data.

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INTRODUCTION

A serious problem usually encountered when comparing predicted with measured transmission loss is the lack of accurate environmental data for input to the acoustic model. This problem becomes more significant in the vicinity of oceanic fronts where drastic changes in vertical and horizontal sound speed structure often occur.

During May 1978, simultaneous environmental and propagation loss measurements were made along three tracks extending from Slope Water, through the Gulf Stream and into the Sargasso Sea. These data provide a unique opportunity to compare predicted and measured values for transmission loss in this region.

OCEANOGRAPHIC AND ACOUSTIC DATA COLLECTION AND ANALYSIS

USNS LYNCH steamed the tracks shown in figure 1, at an average speed of 14.8 km per hour, while towing an omnidirectional 88.8 Hz CW projector 30 m deep. Expendable bathythermograph (XBT) measurements, from the surface to 760 m depth, were made every 7 km en route, except in the warm core and at the northern boundary of the Gulf Stream where XBTs were recorded every 1.5 km. The ship's position was determined to within ± 1 km during each transit using Loran C and satellite navigation systems.

Environmental data collected by USNS LYNCH were supplemented with sound velocimeter data (surface to 850 m), XBT data (surface to 760 m), and salinity/temperature/depth system (STD) casts to 3000 m depth from USNS BARTLETT. Also temperature observations from airborne

expendable bathythermographs were made to a depth of 300 m from a research aircraft. Satellite imagery confirmed that there was no shift in Gulf Stream position along the transect during the period of data collection, thus permitting use of all available data to reconstruct oceanographic conditions during the experiment.

A temperature cross section through the Gulf Stream is shown in figure 2. Note the entrainment of cold Shelf Water at the Gulf Stream North Wall and the well defined warm core. A sound velocity section along a 900 km track, extending from Slope Water through the Sargasso Sea, is shown in figure 3. This graphic was prepared using STD data to calculate sound speeds with Wilson's Equation.[1,2] From figure 3 it can be seen that the deep sound channel (DSC) axis deepens from about 500 m in Slope Water to about 1300 m in the Sargasso Sea. The shallow sound channel (SSC) axis shoals from about 300 m in the Gulf Stream to about 100 m in the Sargasso Sea. A significant increase in sound velocity occurs across the North Wall with the largest horizontal gradient occurring in the upper 800m. Selected sound velocity profiles for Slope Water, the North Wall, the warm core, and the Sargasso Sea are presented in figure 4. For a sound source at 30 m depth excess of about 400, 1700, and 700 m is present in Slope Water, the North Wall and the Sargasso Sea respectively. No depth excess is present in the warm core.

Transmission loss data, from the 88.8 Hz projector towed by LYNCH, was measured through a bottom-mounted, omnidirectional hydrophone situated near the DSC axis near Bermuda. The analog signal from the

hydrophone was transmitted on-line to a computer and converted to digital form. A value of transmission loss was computed for contiguous 80 second samples. Then, a continuous 20 minute sliding average was calculated (equivalent to approximately 4.9 km distance traveled) to produce a plot of transmission loss as a function of time. Because the speed and position of LYNCH were always known, transmission loss as a function of range could also be computed. The acoustic projector was turned off periodically to measure background noise at the receiver, in order to determine signal excess.

MEASURED DATA AND RAY TRACES

Transmission loss measured during the three transits shown in figure 1 are presented in figure 5. The large gaps in the data were caused by high sea states when the projector could not be towed. The smaller gaps are when the projector was turned off for background noise measurements. Referring to figure 1 it can be seen that the three tracks across the Gulf Stream are of different lengths. This causes the prominent features of the Gulf Stream in each curve to be slightly displaced in range from each other.

At ranges where there is data from all three projector tows agreement in the shape of the curves is good. The transmission loss levels are generally clustered within 5 dB of each other. The major features of the curves show sound propagation gradually deteriorating as the source moves through the Gulf Stream towards the North Wall. At the North Wall propagation improves dramatically and then

deteriorates for a brief period before resuming levels comparable to those in the Sargasso Sea. Transmission loss increases from about 108 dB in the Sargasso Sea to about 120 dB near the North Wall. At the North Wall transmission loss decreases by about 10 to 15 dB within a few kilometers and averages around 108 dB in Slope Water.

Ray traces from the Germinating Ray-Acoustic Simulation System (GRASS) model[3,4] are used to explain the experimental results and are shown in figure 6. GRASS is a ray-type variable bottom, multiple sound velocity range dependent model. The ray fan emitted from a source at 30 m was limited to an angle of $\pm 20^{\circ}$ from the horizontal, with individual rays spaced at 1° increments. A ray was terminated if back-scattered, or after 10 surface reflections or bottom bounces.

The ray traces presented in figure 6 are for a sound source located in the Sargasso Sea, the warm core and the North Wall of the Gulf Stream, and in Slope Water. In the Sargasso Sea the long range propagation paths are divided between SSC and refracted surface reflected (RSR) paths. The RSR paths generate convergence zones at or near the sea surface at about 60 km intervals. The SSC paths are caused by a negative sound velocity gradient lying directly above a positive sound velocity gradient. This feature occurs in the upper 500 m and can be seen in figure 4d.

In the warm core no depth excess is present due to the high near surface sound velocity. This lack of depth excess, combined with the steep downward refraction due to the large negative gradients of the sound velocity profiles couples most of the energy into bottom bounce

surface reflected propagation. These propagation paths suffer large attenuation because of numerous bottom bounces, which accounts for the high transmission loss exhibited in the measured data.

At the North Wall and in Slope Water the rays follow the isovelocity curves shown in figure 3 and are coupled into the DSC. The Shelf Water entrainment shown in figure 2 enhances this effect. This coupling of sound energy into the DSC accounts for the good propagation in these regions shown in the experimental data. Submerged caustics are formed at about 700 m. The ranges of these caustics relative to the receiving hydrophone determine the amplitude of the received signal and account for the large fluctuations occurring in the data.

MEASURED AND PREDICTED DATA

Predicted transmission loss was computed using the GRASS model and the Brock Parabolic Equation (PE) Transmission Loss Model.[5,6] These results are compared to the measured data from track 1 in figure 1 and are presented in figure 7. The most complete environmental data set was measured during the experiment along this track and was used as input to the models.

The PE model is a wave-type variable bottom, multiple sound velocity range dependent model which assumes radiation to be predominantly in the horizontal plane with no reflection of energy from the bottom. It is therefore best suited for environments where bottom bounce propagation has no significant effect on the total

acoustic field. Interaction with the bottom is permissible if the energy in the bottom is restricted entirely to refractive paths. Furthermore, the incident energy at the bottom must have a grazing angle no greater than 40^{o}. Runs were made varying the maximum grazing angle from 0^{o} to 40^{o}. The best fit to the experimental data was obtained at 30^{o}.

Both models compute transmission loss forward in range from a fixed sound source. This geometric configuration is the reverse of the experimental geometry where the receiver was fixed and the sound source was moved. In order to provide continuous transmission loss data as a function of range and to limit the number of computer runs to define the transmission loss curves the principle of reciprocity was invoked. This required reversing the positions of the source and the receiver as input parameters to the models.

For the GRASS transmission loss predictions the model was executed for a ray fan from the source of $\pm 89^{o}$ in $.5^{o}$ increments (357 total rays). All rays were terminated after either 30 surface hits or 4 bottom bounces. Even with this well defined ray spacing the agreement to the experimental data was poor. The GRASS model, while very useful in showing which ray families contribute energy to the received signal, is not suitable for transmission loss predictions because of inherent inaccuracies associated with ray-type models.[3,7] The convergence zones in the Sargasso Sea are exaggerated in intensity (which is to be expected from a ray-type model)[3] and are separated by about 60 km. The measured data shows well defined convergence zones at 260 and

325 km, with a probable one at 525 km, which gives a separation of about 65 km. In the Gulf Stream GRASS fails to predict the poor sound propagation which is evident in the experimental data shown in figure 5.

The PE model predicts convergence zone spacing of about 70 km. This is 5 km greater than the observed convergence zone spacing in the experimental data. The PE model is very sensitive to the environmental inputs and if they differ slightly from the actual environment the convergence zone spacing will be affected, but not the intensities.[8] Referring to figure 7, the PE model convergence zones closest in range to the measured zones are low by 2 to 5 dB compared to the measured transmission loss.

In the Gulf Stream the PE model overestimates transmission loss. All energy incident upon the bottom with grazing angles greater than 30° suffers an infinite attenuation. Even with this limitation the model clearly predicts the gradual degrading of sound propagation as the source moves from the southern edge to the North Wall. At the North Wall and beyond the PE model shows reestablishment of good sound transmission and is within 1 dB of the measured peak at the North Wall.

Figure 8 presents a comparison between PE runs for an infinitely attenuating bottom and one that will refract energy with bottom grazing angles of not more than 30°. The major differences between the two predictions occur at ranges where bottom interaction paths contribute significantly to the received signal, that is when the

source is relatively near the receiver or in the Gulf Stream. It should be noted that the PE model is best suited for environments which exclusively support waterborne propagation paths. When a refractive bottom is included, the model is dealing with an environment that taxes its capability.[5,8]

The bar appearing in the measured data at about 600 km (figure 7) is the result of the sound source remaining almost stationary (± 1 km) for a period of 2 hours. During this interval transmission loss varied by about 7 dB, demonstrating that long range sound propagation is a time varying phemomenon. Fluctuations in the received signal can be caused by movement of random inhomogeneities in the medium, which alter propagation paths.[9] Since PE is a time independent model, exact correspondence between measured and predicted transmission loss cannot be obtained.

SUMMARY

Experimental data show high transmission loss when a sound source is located in the Gulf Stream. In this region energy is predominantly coupled into bottom bounce propagation paths. These paths cause high transmission loss due to the attenuation suffered at each bottom bounce. The mechanisms responsible for generating these paths are the high near surface sound velocity gradients between the surface and 250 m, which severely refract energy towards the bottom.

The PE model was more successful than the GRASS model in predicting

transmission loss. However, the GRASS model provided useful ray traces for determining which ray families dominated the received signal. By using GRASS for ray traces and PE for predicted transmission loss an understanding of acoustic propagation through the Gulf Stream was achieved.

ACKNOWLEDGEMENTS

The authors thank Ray Partridge for obtaining the GRASS graphics, Glen Voorheis for the illustrations, and Laura Allen and B. J. Dauro for preparation of the manuscript.

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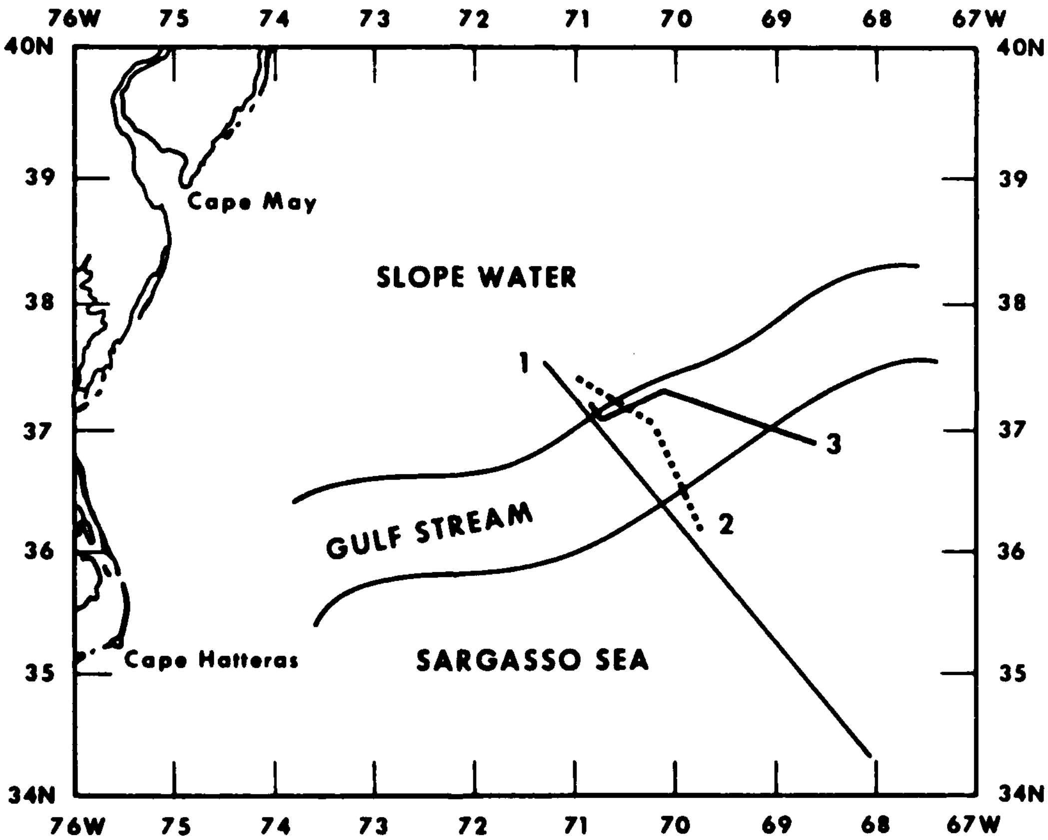

Figure 1. Experimental tracks

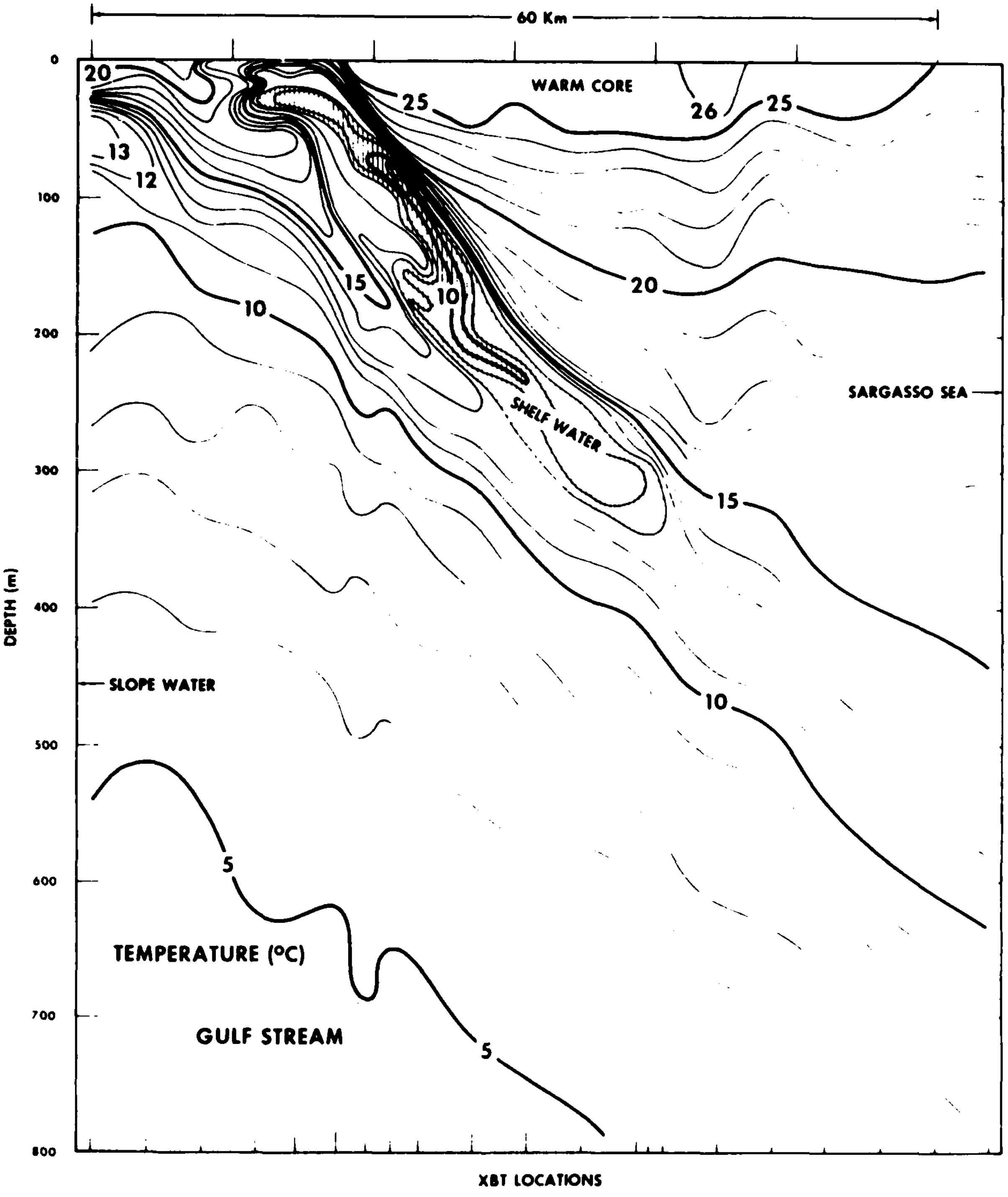

Figure 2. Temperature cross section

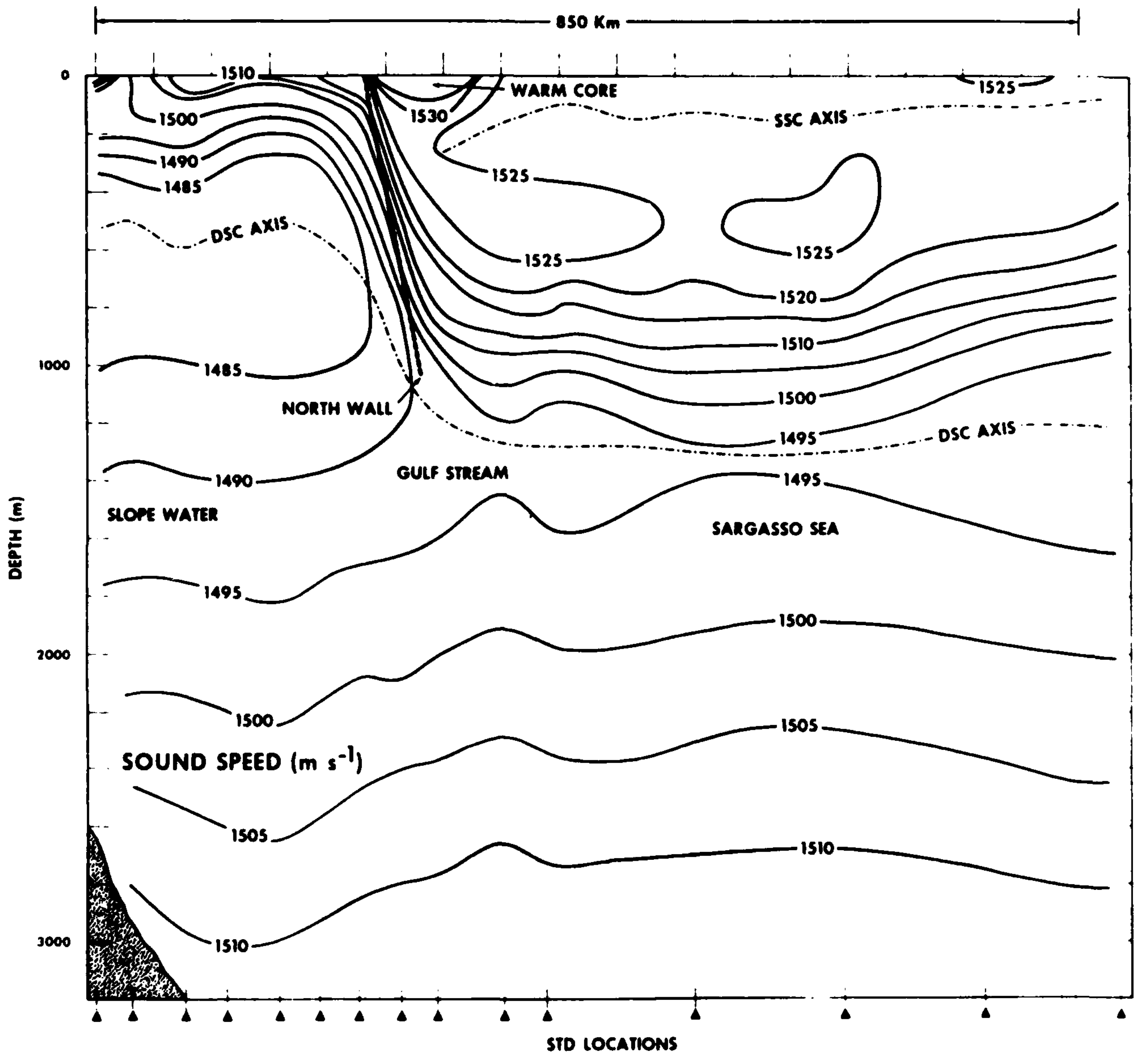

Figure 3. Sound velocity section

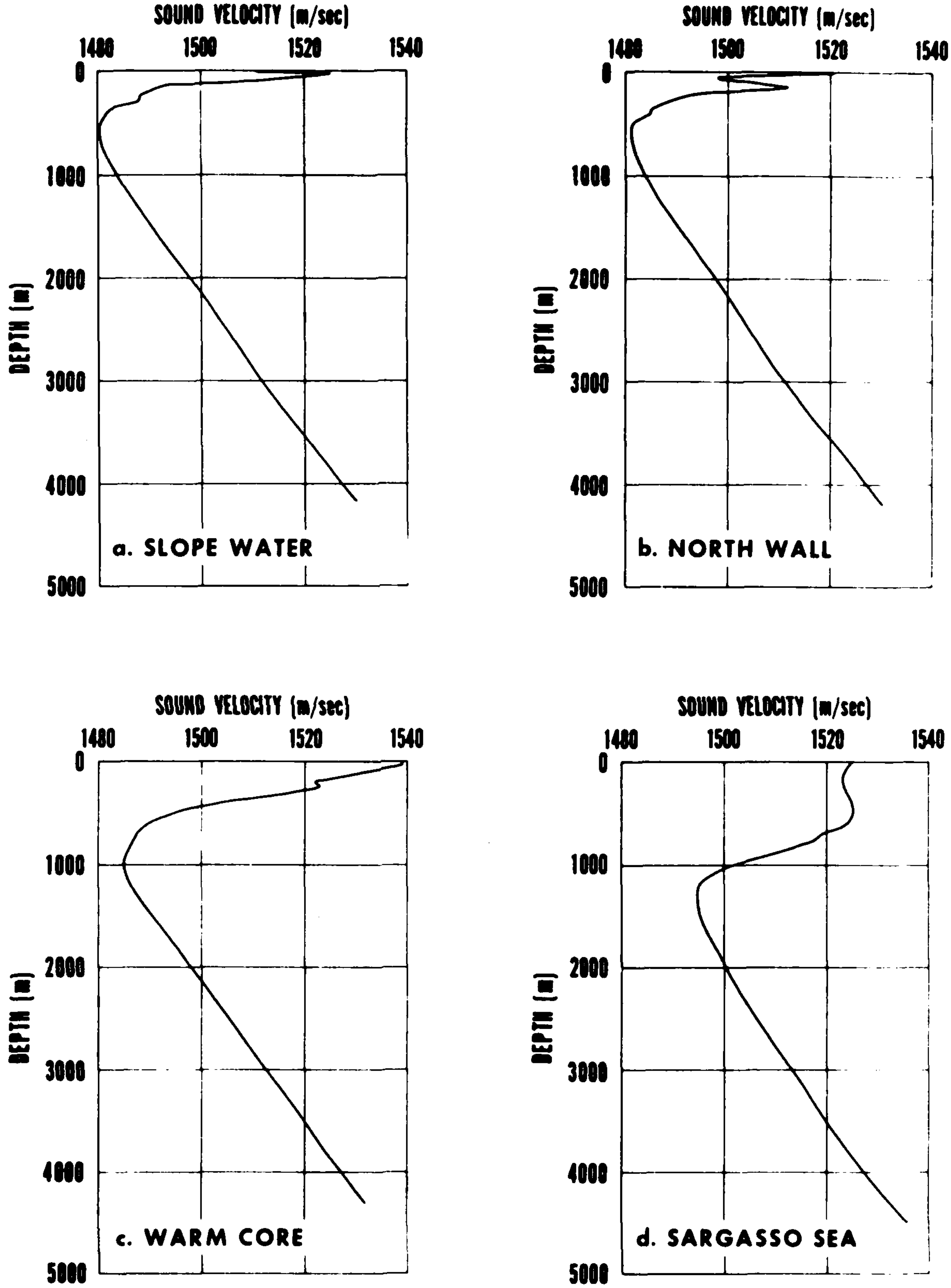

Figure 4. Sound velocity profiles

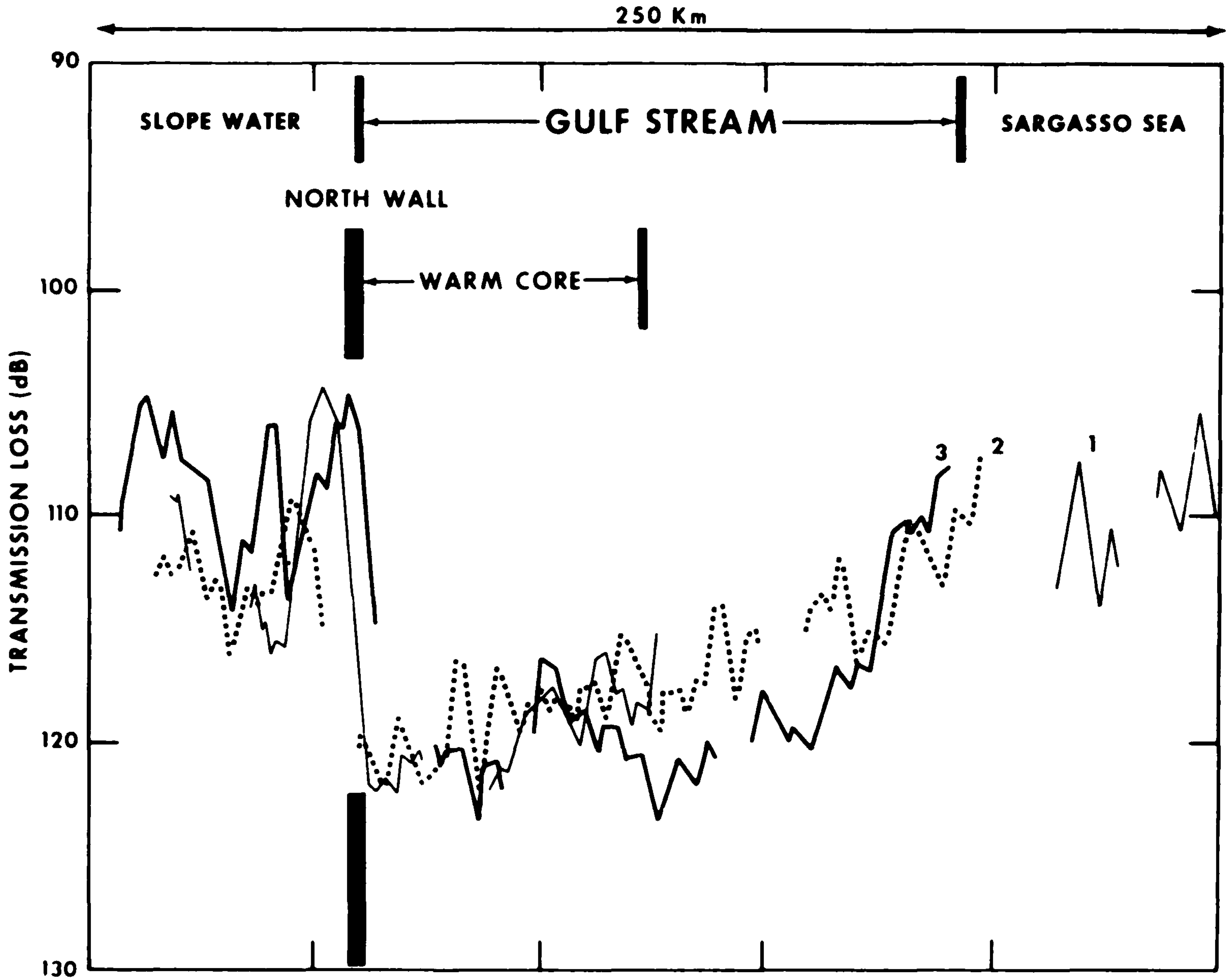

Figure 5. Measured transmission loss

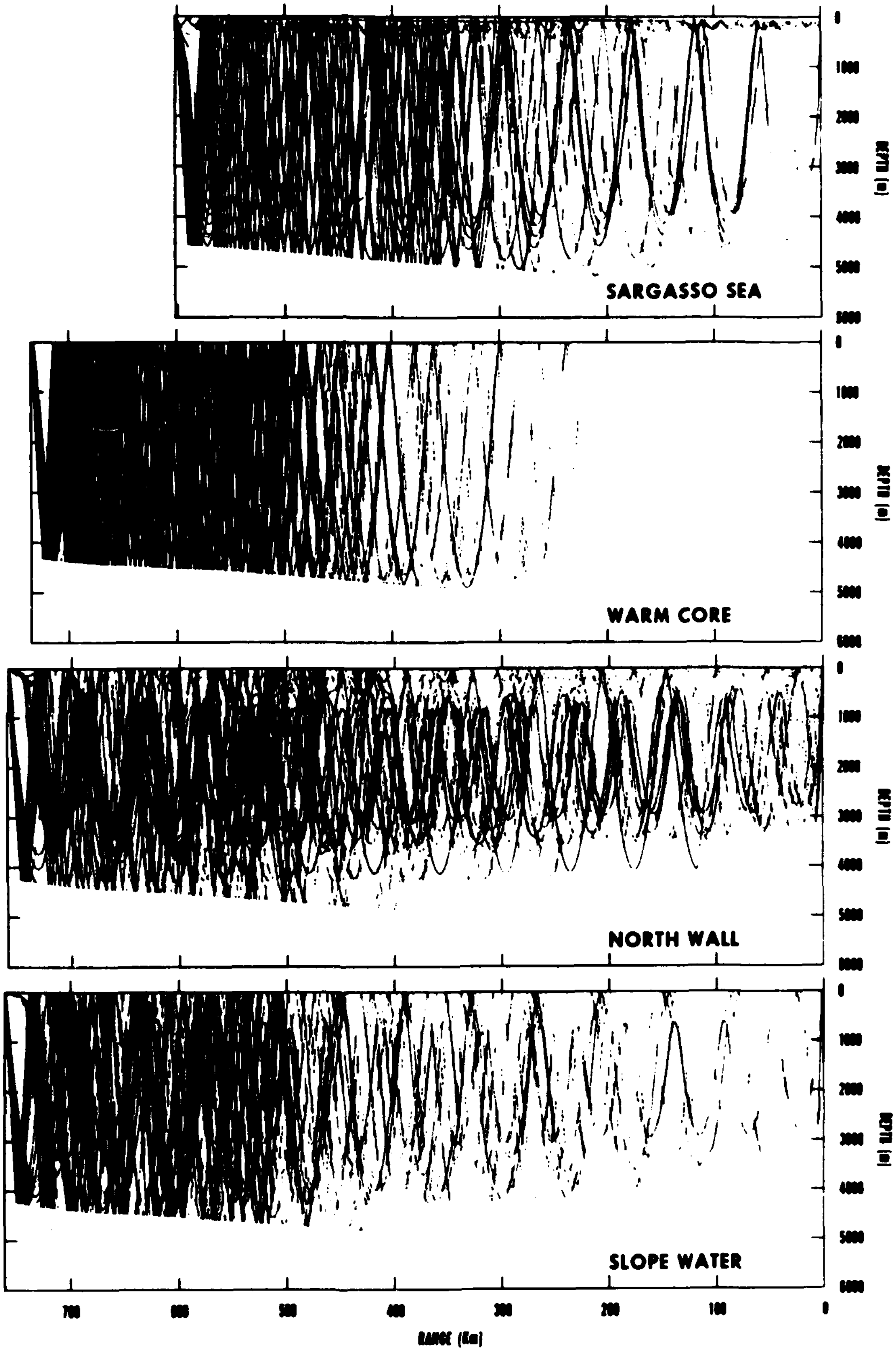

Figure 6. Ray traces
(with source in Sargasso, warm core, North Wall and Slope Water)

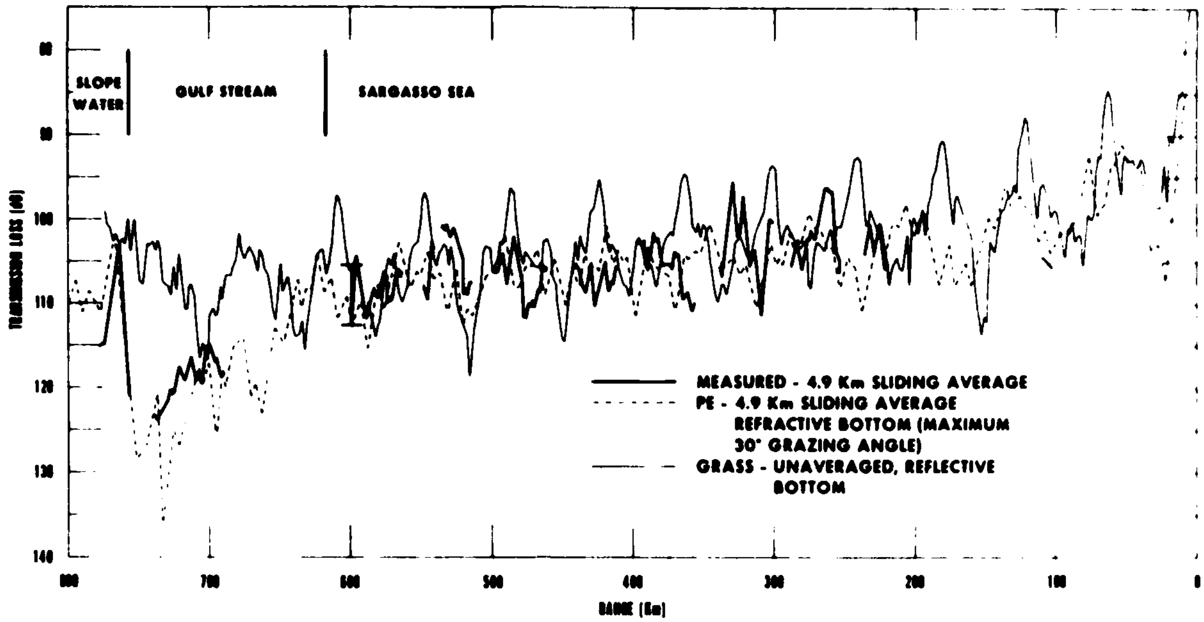

Figure 7. Measured and predicted transmission loss

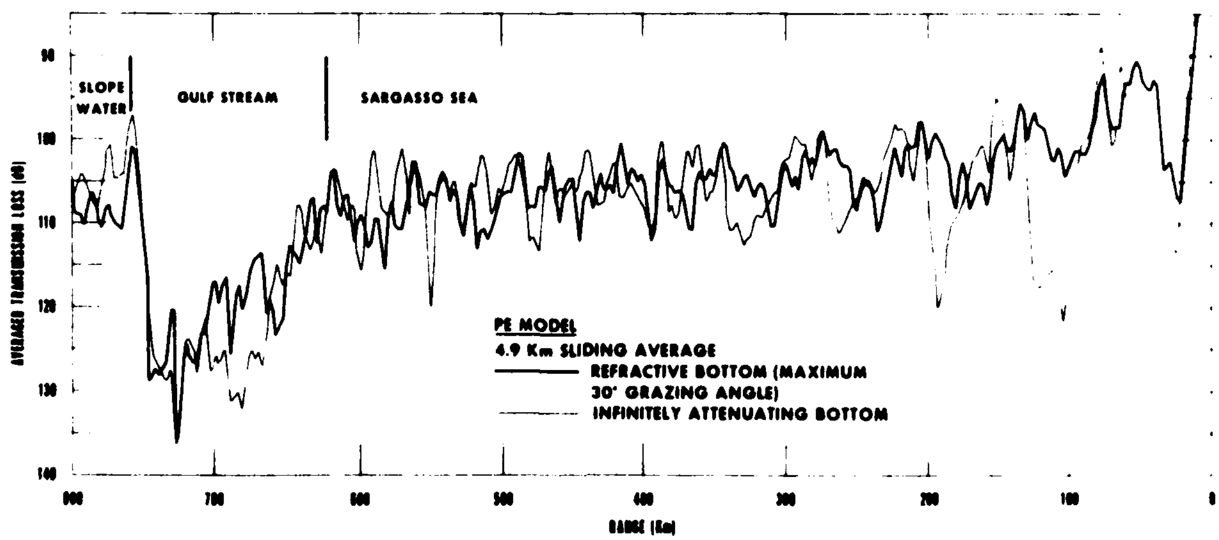

Figure 8. Predicted transmission loss with and without bottom

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